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EXPLOSIVE-METAL COMPOSITES AND ELECTRICAL SWITCH TECHNOLOGY.(U)

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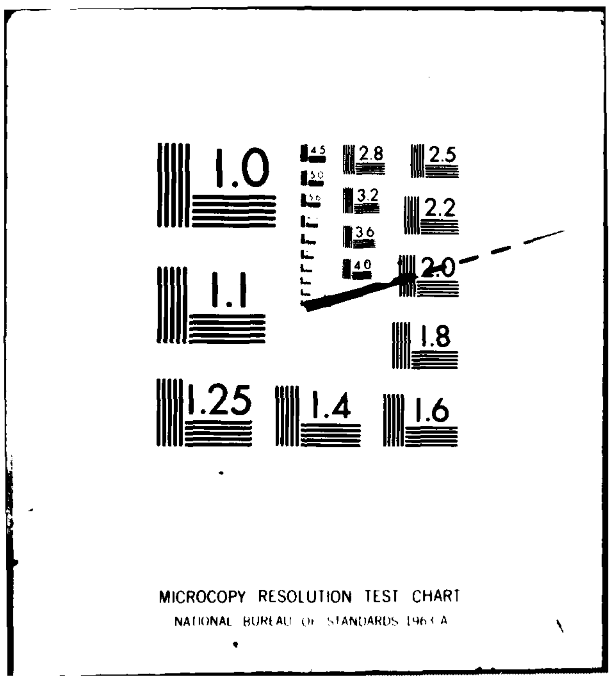
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EXPLOSIVE-METAL COMPOSITES AND ELECTRICAL SWITCH TECHNOLOGY

BY M. J. FRANKEL P. J. DiBONA

RESEARCH AND TECHNOLOGY DEPARTMENT

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A number of different explosive opening switch concepts were investigated. The fabrication of a composite material by the impregnation of a porous metallic matrix by an explosive utilizing a vacuum melt cast technique was demonstrated. Successful initiation and steady detonation wave propagation was demonstrated with use of the Jacobs rapid framing camera while the electrical conductivity through the sample was measured with an oscilloscope. This type of switch is shown to have the potential of

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This work was supported by the U.S. Air Force Office of Scientific Research, Program Element 61102F, Task #2301/A6, FY80.

FOREWORD

A number of different explosive opening switch concepts were investigated. The fabrication of a composite material by the impregnation of a porous metallic matrix by an explosive utilizing a vacuum melt cast technique was demonstrated. Successful initiation and steady detonation wave propagation was demonstrated with use of the Jacobs rapid framing camera while the electrical conductivity through the sample was measured with an oscilloscope. This type of switch is shown to have the potential of switching large electrical currents in times on the order of 10 μs with savings in weight and volume as compared to the geometries used in other explosive switches.

This work was supported by the U.S. Air Force Office of Scientific Research, Program Element 61102F, Task #2301/A6, FY80.

J. F. PROCTOR
By direction

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EXPLOSIVE-METAL COMPOSITES AND ELECTRICAL SWITCH TECHNOLOGY

M. J. FRANKEL AND P. J. DIBONA

BACKGROUND

The development of high power opening switches is of singular importance for emerging pulse power technologies. Explosive opening switches were developed as a more rapid alternative to mechanical circuit breakers. In a typical explosive switch configuration[1] the current is interrupted by using an explosive to sever a conductor by forcing it against cutting rings (See Fig. 1). Recently a new explosive switch concept was reported by Laironov[2] in the Soviet Union whereby the explosive and conductor comprised the same element. This was reportedly achieved by mixing a 10% by weight explosive with 90% by weight (50/50 by volume) copper powder in an undescribed metallugical process. This concept obviates the need for cutting dyes and bending rings used in conventional explosive switches and should result in substantial weight and volume advantages as well as more rapid and efficient current interruption capability. The objective of this program was to investigate the fabrication of a composite material with the electrical properties of a metal and the energetic properties of an explosive for use as a fast opening electrical switch.

APPROACH

Three concepts were considered and explored with varying degrees of emphasis. These are described briefly in this section.

A. PRESSED POWDERS

In the first approach, a composite material composed of powdered PETN explosive (10% by weight) was mixed homogeneously with powdered copper (90% by weight, 50/50 by volume) and isostatically

[1]Ford, R. D. and Vitkovitsky, I., "Explosively Actuated 100 kA Opening Switch for High Voltage Applicators," NRL Memorandum Report 3561, July 1977.

[2]Larianov, B. A., "Some Methods of Increasing the Response of Fast Breakers," Proc. All-Union Conf. Eng. Problems of Fusion Reactors, USSR, July 1977.

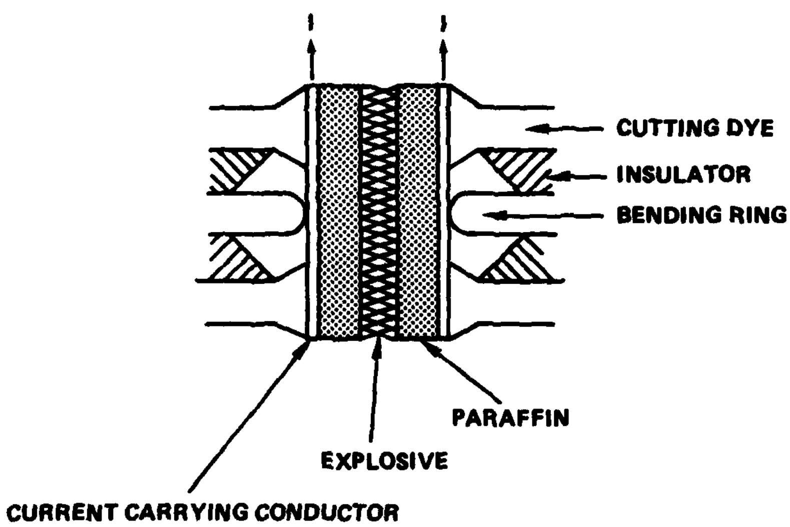

FIGURE 1 CONVENTIONAL EXPLOSIVE SWITCH CONFIGURATION

pressed at 100,000 psi. A cylindrical sample 0.5" diameter by 2.0" long was produced as well as a number of inert samples with Teflon powder replacing the energetic PETN.

B. POWDER FRAGMENTATION

Another approach involved the fabrication of an explosive switch in the geometry shown in Figure 2. The outer current conducting shell was fabricated from a copper powder by pressing (at 100,000 psi) and sintering. This concept, suggested by A. Rozner, revolved around the possibility that the interaction of the shell material with the expanding shock wave fom the central explosive would reduce the shell to a facsimile of its initial powdered form. With the ready and extreme fragmentation of the conducting element, the need for spatially bulky and operationally time consuming bending rings and cutting dyes would be eliminated.

C. IMPREGNATED METAL MATRIX

In the third concept a porous, foamed metallic matrix with excellent conductive properties and mechanical strength was impregnated with an explosive. The metallic matrix material is available as a patented commercial product, Duocel, of ERG Inc. of Oakland, Ca. Duocel is manufactured by the directional solidification of metal from a super heated liquidus state in an environment of inerts and vacuum. The resulting material has a reticulated structure of open duodecahedronal shaped cells connected by continuous solid metal ligaments (See Fig. 3). Both the density of the metal and the pore size may be varied independently. Detonability of the impregnated composite material and the electrical characteristics were then investigated. The expectation is that the characteristic closing time for this switch would approximate the time a typical detonation wave might take to propagate down the length of the switch. At typical velocities of 8 mm/μs one might hope to design a two inch long switch that would close in 6 μs and hold off 50 kv, taking the breakdown of air at about 25 kv/cm.

RESULTS AND DISCUSSION

1. The composite samples formed from the powdered copper and explosive (and copper/Teflon) all proved to have a resistance on the order of one ohm, far too high for use as a conducting element in a circuit. The most likely way of substantially improving the conductivity would be to heat treat the samples. This did not, however, seem immediately promising since the ignition temperature of PETN at about 145°C seems to be far below the temperature at which the copper grains would begin to soften and flow (the melting point of copper is over 1000°C). Laironov reports manufacturing samples which could be heated briefly to 300°C without exploding but this also seemed problematic given the relatively low ignition temperature of PETN. Given the constraints of time and the budget it was decided at this point to explore the other two options.

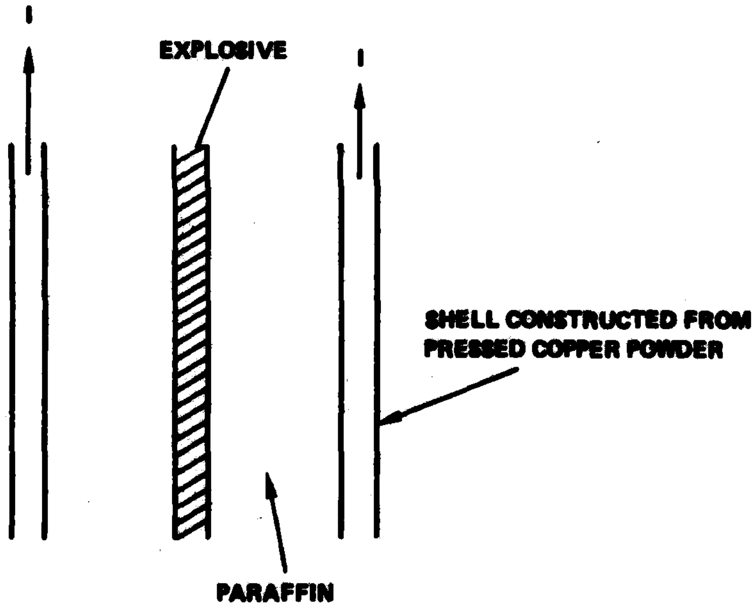

FIGURE 2 FRAGMENTATION SWITCH CONCEPT

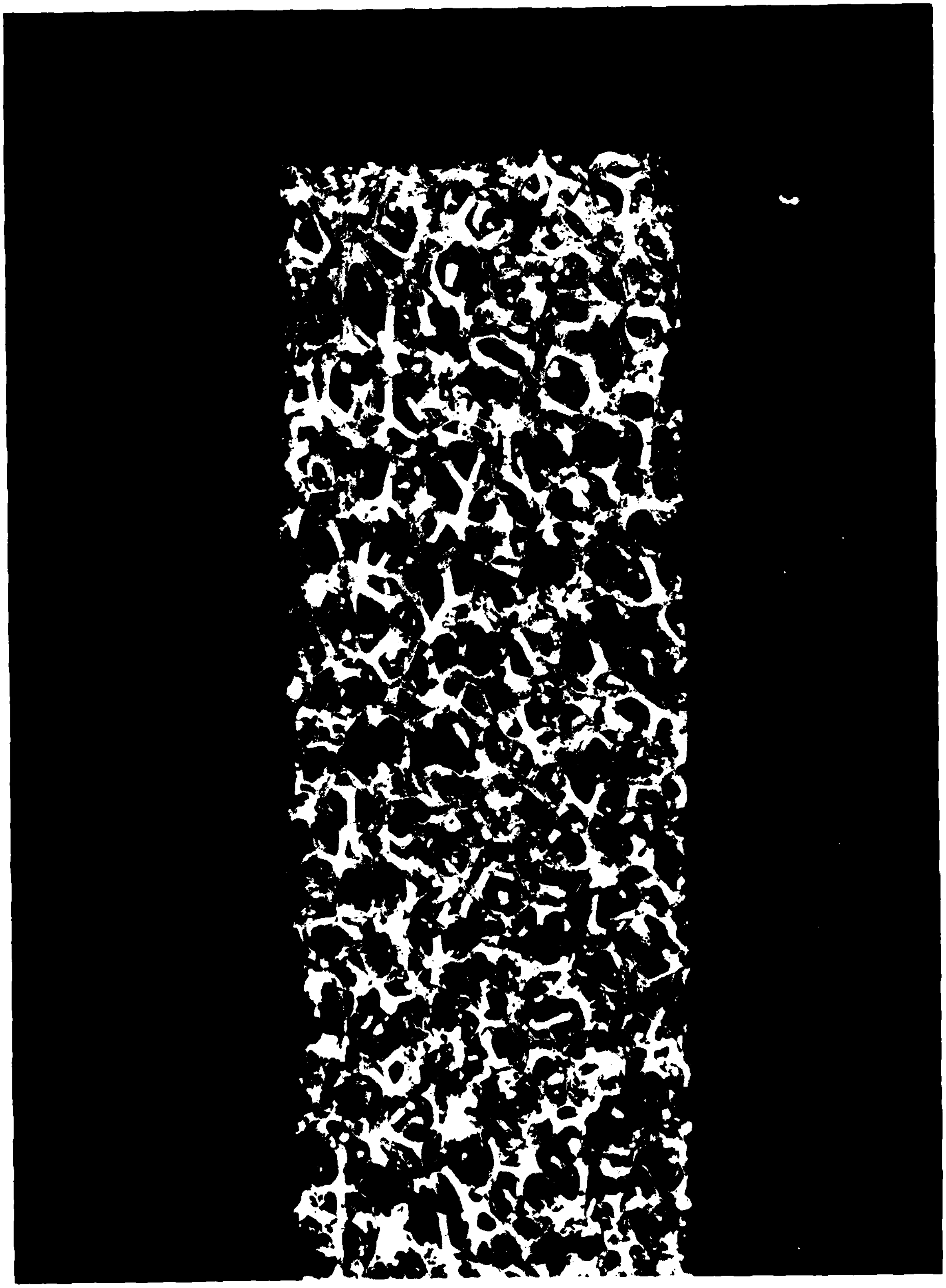

FIGURE 3 ALUMINUM MATRIX MATERIAL

2. A cylindrical shell (2" long, 1/2" diameter and 1/8" thick) was fabricated from copper powder by pressing at 1000,000 psi and sintering. The electrical conductivity of the shell approximated that of solid copper. The shell was then loaded with a central line charge of a powerful explosive (PBX-9404) and wax as shown in Figure 2. The explosive was detonated and the resulting shell fragmentation examined. The collected shell fragments are shown in Figure 4. It is evident that, far from fragmenting back into a powdered state, the shell broke up into relatively large sized chunks, some over a 1/2" long. The shell thus responded to the shock loading in a manner similar to that expected from a solid metal manufactured from rolled sheets. Evidently the high pressure pressing combined with sintering produced conditions of flow which erased the internal grain boundaries and all memory of its powdered origins. One option would have been to back off on the temperature and pressure to prevent flow from occurring while maintaining a relatively high conductivity, looking for an optimal tradeoff between fragmentation performance and conductivity. While this trial and error approach still seems quite feasible, we decided instead to pursue a third explosive switch concept which involved the use of impregnated porous metal matrixes.

3. A number of samples of commercially available Duocel were acquired from ERG Inc. The materials were 6% of normal bulk density with a pore density of about 10 pores per inch. Typical pore dimensions were 1-2 mm. The first sample of dimensions 3/4" x 3/4" x 4" was pre-heated to the temperature of molten TNT (Trinitrotoluene) and loaded with TNT in vacuum, using a melt cast technique. It was felt desirable to try loading with pure meltable explosive so that problems of particulate matter clogging the porous matrix during the loading process could be avoided. To test the loading capability two metal samples were loaded from melt-cast TNT. One of the samples was cut open and subjected to an "eyeball" examination. No unfilled pockets were observed in the explosive cross-section. The other loaded sample was then investigated for detonability. This was accomplished by initiating the sample at one end with an RP-80 detonator and data sheet booster and observing the progress of the detonation wave with a high speed Jacobs framing camera. After the shot, the sample was recovered. As shown in Figure 5, the detonation wave did not propagate down the length of the sample, but instead reaction was extinguished after propagating about an inch into the sample. The twisted edges of the metal matrix can be seen protruding from the charge at the point where the reaction was extinguished. That the reaction did not propagate itself down the length of the sample was, in retrospect, no surprise since the cross-section of the sample was less than the listed 2.7 cm failure diameter of TNT. A third sample of similar dimension was prepared and loaded with another meltable explosive, TNB (Trinitrotoluene). The tested failure diameter of TNB is < 3 mm,

FIGURE 4 COLLECTED SHELL FRAGMENTS

FIGURE 5 QUENCHED DETONATION IN TNT/ALUMINUM

considerably less than the roughly 3/4" square cross-section of Sample 3. The detonation wave again failed to propagate down the charge. Two possible reasons for this detonation failure were suggested. The first involves the use of a cast explosive which is typically less sensitive and has a larger failure diameter than the values listed for pressed explosives. Another possibility involves the nature the metal explosive system which was being initiated. Since the explosive effectively filled pores within the metal matrix, it is possible that the appropriate dimension to consider for failure purposes is the mean size of a single pore which contains the explosive. At typical sizes of 1-2 mm this would fall below the required diameter problem a cylindrical, 1/4" diameter hole was bored down the center of sample number four and the sample was loaded with Pentolite, a sensitive explosive composition containing equal volume percentages of TNT and PETN. This sample was successfully detonated. A 10 amp current was applied to the sample during initiation by a 10 volt power supply in series with a one ohm resistor (Fig. 6). An oscilloscope trace of the voltage is shown in Figure 3. While the circuit trace shows a good deal of bounce due to reflections from the impedance mismatched alligator clip-cable interfaces, the current is shown being driven to zero in about six microseconds. A final sample, without the helpful central shaft of pure explosive, was loaded with Pentolite and initiated. No electrical trace was obtained because of failure of the oscilloscope to trigger, but a film record obtained with the fast framing (Jacobs) camera is shown in Figure 8. The record shows a detonation wave with a velocity of 8 mm/μs proceeding down the metal-explosive composite material and clearly establishes the detonability of such materials.

CONCLUSIONS

We have demonstrated that explosive loading of metallic matrix materials is feasible and that the resulting composite material remains detonable while simultaneously providing a capability to conduct electricity. We believe that this geometry provides the potential for development of a fast (on the order of three microseconds per inch), high power (25 kv per inch) opening switch for pulse power applications.

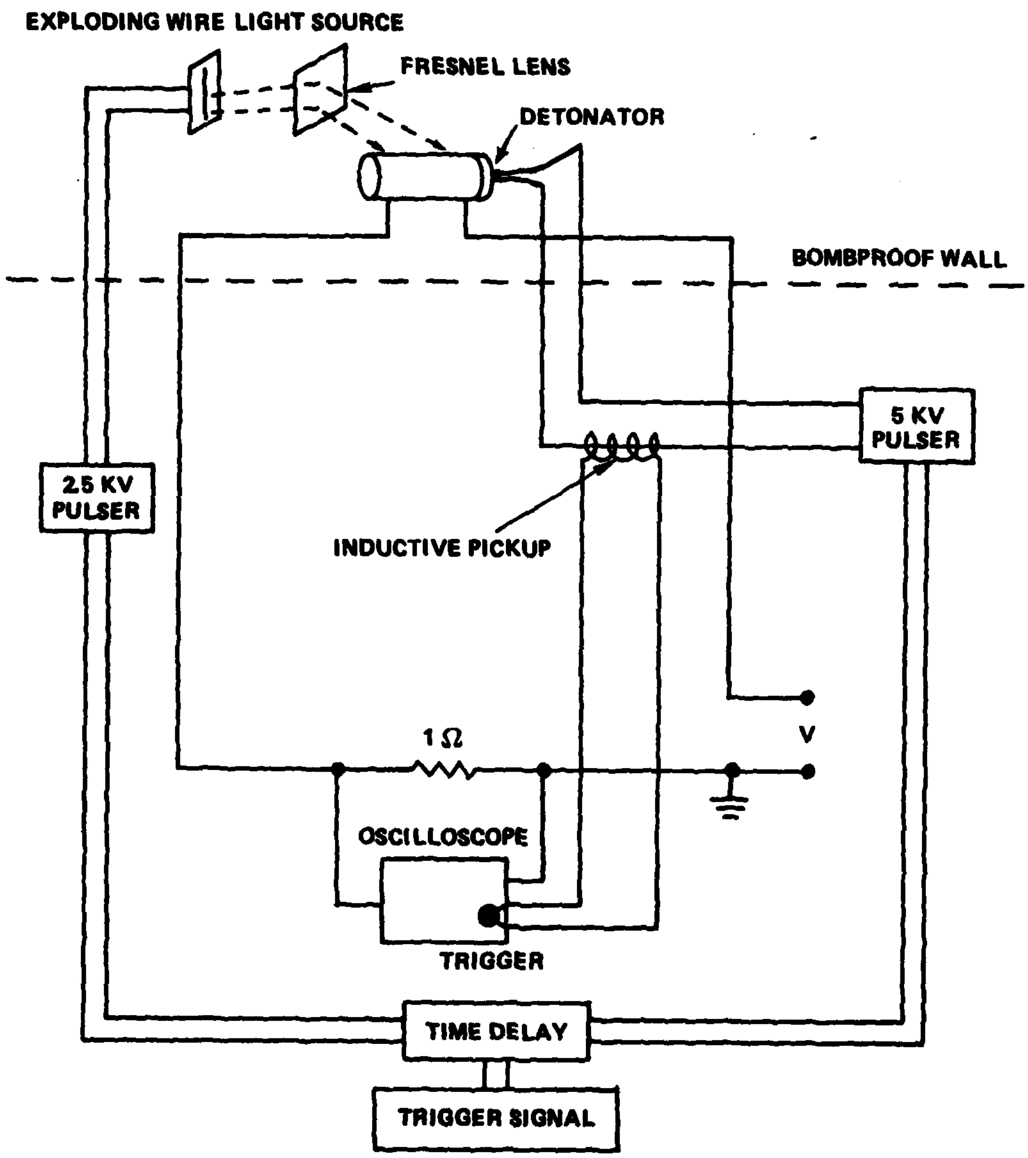

FIGURE 6 CIRCUIT DIAGRAM

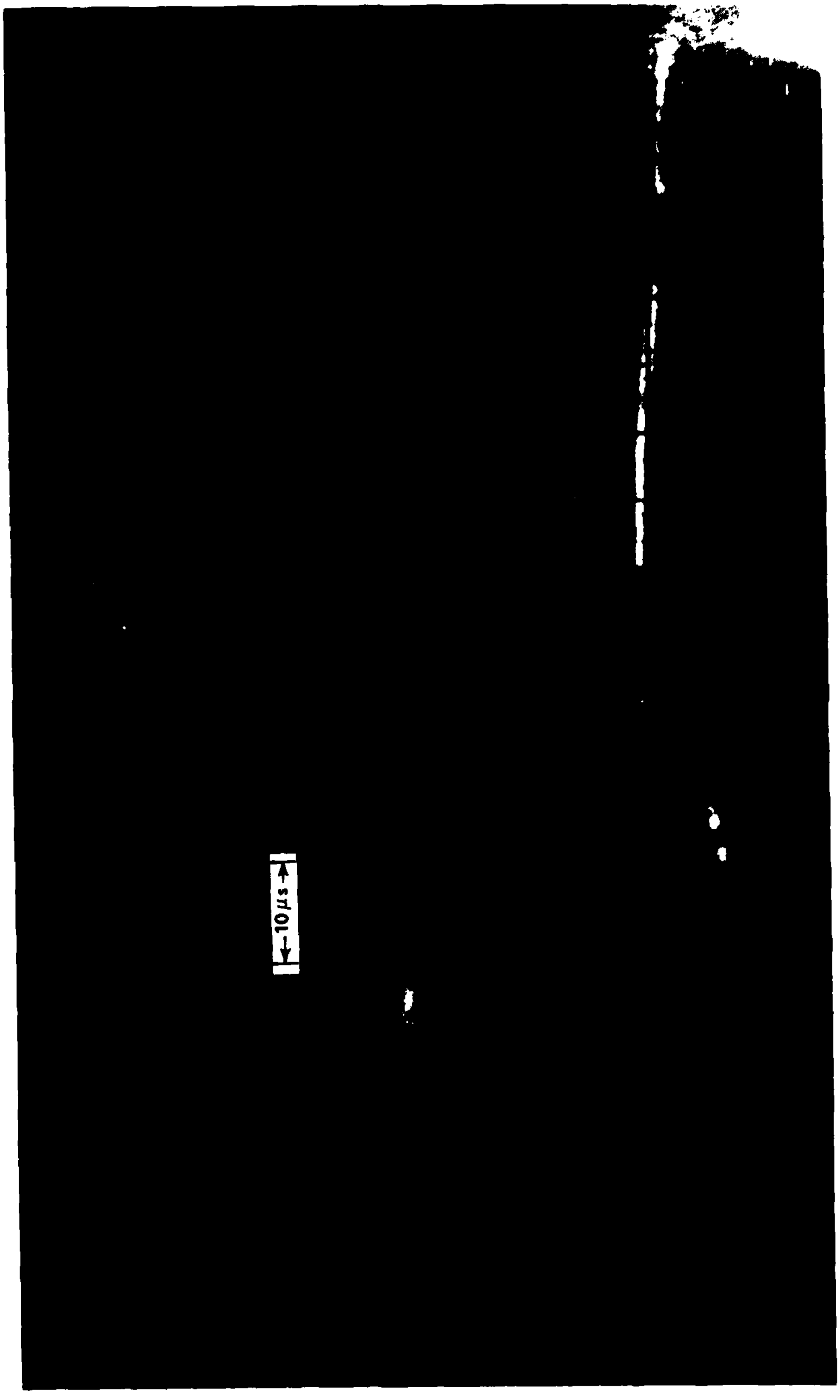

FIGURE 7 OSCILLOSCOPE TRACE

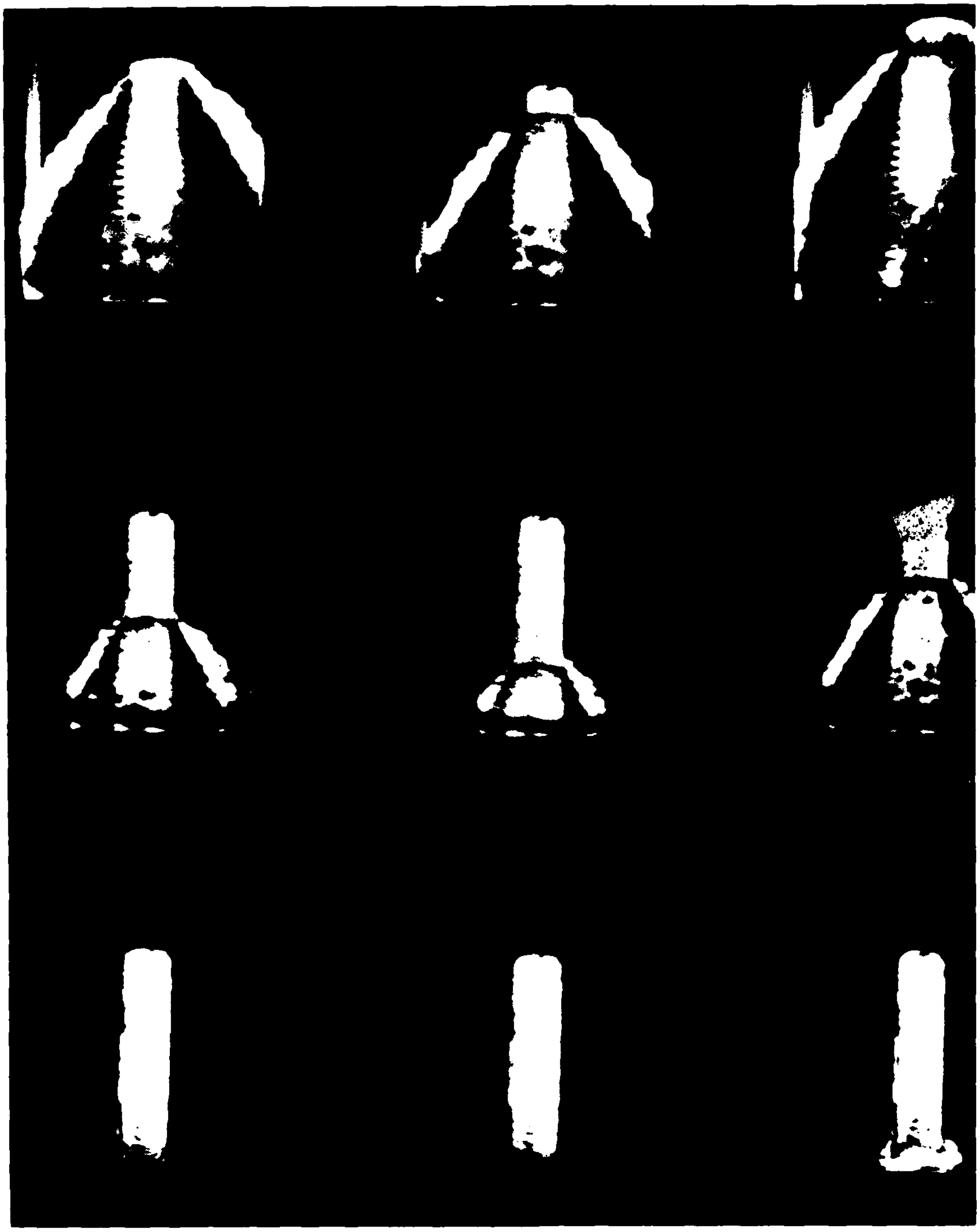

FIGURE 8 STABLE DETONATION IN PENOLITE/ALUMINUM COMPOSITE - JACOBS CAMERA RECORD

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1. Ford, R. D. and Vitkovitsky, I., "Explosively Actuated 100 kA Opening Switch for High Voltage Applicators," NRL Memorandum Report 3561, July 1977.

2. Larianov, B. A., "Some Methods of Increasing the Response of Fast Breakers," Proc. All-Union Conf. Eng. Problems of Fusion Reactors, USSR, July 1977.

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